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MICROSCOPIC AND PHYSICAL ANALYSES OF SELECTED COTTON AND NYLON FABRICS BEFORE AND AFTER ABRASION

by

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CHAPTER I

INTRODUCTION

The wearing qualities of a textile fiber are of concern to almost every consumer of textile products. This investigation was designed to determine the effects of flat abrasive wear on selected service qualities of cotton and nylon fabrics by microscopic and physical analyses. The term wear refers to the effects of many kinds of deteriorating action upon textiles, including abrasion, tensile stress, cuts, microbial attack, chemical damage, and the effect of sunlight. The term abrasion is limited in meaning to describe a rubbing action with relative motion between two materials. McNally and McCord (15) have stated that resistance to abrasive forces of some kind is a factor in almost every textile application. Although abrasion is only a part of wear, they believe that abrasion resistance is the most important factor contributing to the wearing quality of a fabric.

Abrasive action may cause damage to fibers and yarns in the fabric structure. Microscopic examination and the use of photomicrographs are helpful in understanding the mechanical breakdown of fibers, yarns, and fabrics. Unfortunately, few photomicrographic studies of abraded fabrics have been done. The damage imparted by abrasion may result in several changes in the physical properties of a fabric. Most studies of abrasion resistance relate only one physical property to the abrasive action.

Research is needed to determine the effects of progressive

abrasive action upon a range of physical properties, and to determine the ways in which these effects occur. The objectives of this investigation were to:

1. Determine, by microscopic observation and the use of photomicrographs, the kind and degree of damage on cotton and nylon fibers, yarns, and fabrics as a result of differing intensities of abrasion.
2. Determine the effects of varying intensities of abrasion on the strength, weight, and wrinkle recovery properties of cotton and nylon fabrics.
3. Determine relationships between type and extent of fiber and fabric damage due to abrasion, and the effects of abrasion upon selected physical properties of the fabrics.

CHAPTER II

REVIEW OF LITERATURE

Abrasion has been defined previously as a rubbing action between two materials. In the abrasion of textiles, the abrasive action may be flat, with wood, dirt, metal, plastic, or another textile acting as the abradant; or the fabric may be subjected to flex abrasion, where it is repeatedly folded, and rubbed against itself. Both flat and flex abrasion produce some type of stress and consequent deformation within yarns and fibers which leads to the breakdown of the fabric structure. Stresses may vary in type, magnitude, and frequency of occurrence. In an investigation of the abrasion resistance of cotton, McNally and McCord (15) described the types of stresses that destroy fabric structures as shear, tensile, compression, and torsion, and suggested that tensile stresses were the most severe.

In order to resist destruction, it is necessary for a fabric structure to absorb the energy imparted by the occurrence of stresses. There must then be some way for the fabric to release the energy so absorbed, after the stress is removed. As a result of an investigation of the mechanical means whereby abrasive damage occurs, Hamburger (12) suggested that the amount of deformation a fabric can take without rupture depends upon the immediate elastic deflection of the fabric, and upon its delayed deflection, or creep. In an investigation of the effects of the structural geometry of fabrics on their resistance to abrasion, Backer (2) stated that a fiber that is not held tightly by

the yarn structure will be able to elongate, slip under a protuberance of an abrasive surface, and return to its original position. Since different fibers recover at different speeds, the relative degree of recovery depends somewhat upon the frequency of contact between the protuberances and the fiber.

Factors Influencing Abrasion

McNally and McCord (15) have attributed the mechanical breakdown of textiles during abrasion to three factors: frictional wear, cutting, and plucking or snagging of fibers. These may occur separately, or in various combinations. Frictional wear occurs most often where the abradant is smooth, and the fibers are held firmly by the yarn structure. They also suggested that molecular forces act as welds between two solid surfaces in close contact, and resist any movement between the two surfaces. Stout and Moseman (17) have stated that these welds, or cohesive forces, may operate in several places: between the abradant and the fiber, between contiguous fibers, and between the structural components of the fibers themselves. According to Backer (2) the magnitude of frictional forces is related to the tensile forces set up along a fiber axis, and depends on the load at the contact points, not upon the area of contact.

It has been found by Backer (2) that an abrasive surface having sharp, small projections will cut individual fibers, eventually destroying the fabric structure. Stoll (18) has suggested that a fine abradant is able to break up the internal cohesion of the fiber, and thus cause it

to rupture. Plucking or snagging is more likely to occur when a large, blunt projection travels across the face of a fabric. It was found by Hamburger (12) that fabrics with loose weaves and yarns with low twist are affected by plucking, as the fibers and yarns are not held tightly by the fabric structure. These fibers may slip out of the fabric completely, or be displaced vertically beneath the path of the abradant (Backer, 2).

The relative effects of the mechanical actions that cause destruction of textiles have been divided by Stoll (18) as follows: plane abrasion, thirty per cent; edge and projection abrasion, twenty per cent; flexing and folding, twenty per cent; tears, twenty per cent; and other mechanical actions, ten per cent. Because there are different ways in which abrasive damage may occur, several methods of determining the abrasion resistance of textiles have been developed. The American Society for Testing and Materials, Committee D-13(1), has listed several different abrasion testing methods, and the instruments which may be used. The Stoll Abrader subjects a specimen to unidirectional reciprocal rubbing and folding over a bar. Specimens may also be inflated over a rubber diaphragm, and subjected to unidirectional or multidirectional rubbing action. The Wyzenbeek Abrader tests flat abrasion by use of an oscillating cylinder. The Taber Abrader also subjects the specimen to flat abrasion, and uses a rotary rubbing action. Fabrics may be subjected to flex abrasion by the Accelerotor, using a variety of abrasive surfaces at controllable high speeds. The Schiefer Abrasion Testing Machine makes it possible to produce uniform flat abrasion in every

azimuthal direction. The Schiefer Abrader may use either a cross-cut tungsten tool steel blade abradant, or a spring steel blade abradant.

The degree of abrasive damage is influenced by the conditions under which abrasion is done. Stoll (18) describes the most important conditions as: (a) general condition of the specimen, whether it is wet or dry; (b) the nature of the abradant; (c) tension of the specimen, and the pressure placed upon the specimen; (d) direction and speed of motion; and (e) removal of lint or other debris. These conditions are variable, both from one method of abrasion to another, and within one particular method. All of the conditions must be considered in the analysis of the damage caused by abrasion. In a report of an investigation of the wear resistance of military fabrics in service wear, Kaswell (14) suggested that it is not always necessary for abrasion testing machines to attempt to duplicate wear. Instead, he stated, laboratory induced abrasion may be correlated with service wear, and good predictions of the wear resistance of the fabrics tested may then be made.

The terms fiber geometry and fabric construction refer to gross fiber dimensions, and the manner in which they are arranged in textile structures. McNally and McCord (15) have stated that filaments, long staple fibers, and coarse fibers show slower deterioration because of the opportunity for more cohesion within the fiber. The same principle applies to yarn construction, with fewer fibers in a yarn cross-section lowering the yarn cohesion, and thus its abrasion resistance. It was also found that yarns showing the greatest cohesion tend not to be in a perfectly spherical shape, so that the outer layers of fibers aren't

weakened by being stretched over great distances; usually have larger diameters, in order to distribute the stress to more fibers; and tend to be plied yarns, rather than single.

The structure of the fabric is important in that it determines the surface area exposed to the abradant. Cranshaw, Morton, and Brown (8) have stated that if the crimp of either warp or filling yarns is unbalanced, or the fabric structure causes one set of yarns to predominate on the surface of the cloth, the fabric will tend to show early failure in that direction. Backer and Tanenhaus (3) found that higher numbers of threads per inch in the construction of fabrics tend to increase the number of yarns in contact with the abradant, and distribute the stress over a wider area. Also, there was some evidence that a high degree of twist in a yarn cut down on the number of places where the abrasive surface and the fabric met, and increased the pressure at the contact points. This increased pressure then contributed to the early breakdown of the yarn structure. The bulk modulus of a fabric structure was described by Backer and Tanenhaus (3) as a major factor influencing the contact area of a given load. A low bulk modulus affords high flexibility, and brings many yarn crowns in contact with an abradant before it is fully supported. The load is reduced at each contact point, and lessens the amount of frictional wear, produces less axial stress, and reduces cutting, plucking, and slippage. High bulk modulus increases the frictional resistance of the fabric as it increases the total area of contact between the fabric and abradant.

There are certain properties, inherent in the fiber itself, that

affect the abrasion resistance of the fabric. McNally and McCord (15) proposed that the low elongation of cotton fibers might account for some of their abrasion resistance. As a material is stretched or elongated in one direction, it decreases in size at right angles to the direction of the stress. As a cotton fiber is extended, the angle of fibrillar orientation decreases, and the fibrils become oriented parallel to the fiber axis. New attractive forces are then in operation, and the fibrils are set in this position. The low elongation of cotton, then, prevents the cross-sections of the fibers from becoming small and allowing moderate abrasive forces to develop concentrated stresses. The spiral structure of the cotton fiber was also thought to help its resistance, as not all of the fibrils were at right angles to the abrasive force, and were able to absorb stress with less damage. They also stated that nylons inherent properties of high strength, high elongation, and excellent elasticity contribute to its high abrasion resistance.

Evaluation of Damage Due to Abrasion

Since abrasion involves many factors, the measurement of its damage is a complex problem. Methods of evaluating abrasive damage have traditionally included such means as observing the appearance of the surface of the fabric, measurements of weight loss, changes in thickness, air permeability, stiffness, wrinkle recovery, luster and color, loss in strength, and fiber microscopy.

Microscopic Analyses

Microscopic examination of abraded fabrics is used to determine

the nature of fiber damage that has been caused by abrasion. Clegg (7) microscopically analyzed fibers taken from many types of worn cotton garments, and found examples of fibrillation, transverse cracking, and compression. She also found good correlation between damage incurred during service, and abrasive damage caused by laboratory test methods. Another investigation of abrasive damage to cotton was conducted by DeGrury, Carra, Tripp, and Rollins (9). They used photomicrographs and electron microscopy to investigate the effects of abrasion. Damage was noted in the forms of fibrillation, fragmentation, mashing and bruising of fibers, and sharp transverse breaks. Fibrillation was defined by McNally and McCord (15) as longitudinal fiber separation which occurs to the extent that the fibrillar structure may be seen. This type of failure is thought to occur more often when the fibers are held firmly in the yarn or fabric structure. There are indications that fibrillation is possible because of low energy bonds in the lateral bonding of the longitudinally orientated structures of the cotton fiber. These hydrogen bonds provide natural cleavage planes within the fiber, and supply a convenient place for the destruction of the fiber to start. The application of cross-linked resin finishes was found by DeGrury, Carra, Tripp, and Rollins (9) to increase the strength of the fibers in this direction to such a degree that sharp lateral breaks occurred before fibrillation. McNally and McCord (15) found transverse cracks in cotton fibers that had not been treated with resin finishes. They suggested that these cracks had occurred as a result of bending, flexing, and compression of the fabrics. Bruising occurs when the abrasive action is not as severe

as to cause fibrillation. Clegg (7) noted that bruising, or damage to the outer portion of the primary wall of the fiber, occurred often in the crowns of yarns. She suggested that this was a result of the relative mobility of these yarns, which allowed them to escape from intensive abrasive forces.

Ford (11) studied the effects of strain upon man-made fibers, and found transversely interrupted bands and variations in the thickness and orientation of nylon fibers after the application of stress. He attributed these effects to the formation of internal voids within the fiber, and hypothesized that they had originated as gas bubbles.

Breaking Strength and Elongation

Changes in the breaking strength and elongation of fabrics have been suggested by Hamburger (12) as offering dependable quantitative measurements of abrasive action. Work done by Cranshaw, Morton, and Brown (8), and Ball (4), indicated that although strength decreases as the amount of abrasion increases, the loss does not occur in a direct linear relationship to the amount of abrasion. Stout and Moseman (17) found the greatest elongation loss occurring during the first one hundred strokes of the abradant, but offered no explanation for the loss. Clegg (7) found that the strength loss was primarily caused by the loss of fibers, and damage to the fibers that remained in the fabric structure.

Wrinkle Recovery

In a study of the effects of abrasion on the stiffness and wrinkle recovery of cotton, Buck and McCord (6) established that those

fibers which had a low degree of molecular orientation, and fibers with a large, round cross-section had good resistance to creasing. Douglas (10) stated that abrasion tended to increase the wrinkle recovery of cotton slightly, and attributed it to an increase in yarn crimp.

Weight

It was also suggested by Hamburger (12) that changes in weight could be used successfully as an indication of abrasive damage. Many small fibers and fiber particles are removed from fabrics during abrasion, resulting in a loss of weight. Much fiber damage may occur before a large amount of weight loss is observed, particularly where the fabric structure holds the fibers tightly. It has been noted by Ball (4) that an increase in the weight of some specimens may occur after low abrasive stresses. He attributed this to an increase in the thickness of the fabric due to cut and broken fibers being teased out of the yarn before they were detached from the structure. Douglas (10) advanced a tentative theory that the larger number of fibers on the surface of the fabric increased the ability of the fabric to absorb moisture, and thereby caused a gain in weight.

CHAPTER III

METHOD OF PROCEDURE

Cotton and nylon fabrics, similar in weight and weave, were used to investigate the effects of varying levels of abrasion upon fiber yarn and fabric structures. Cotton was included because of its wide use in today's textile market, and because it has moderate resistance to abrasion. Nylon is generally acknowledged as having the highest resistance to abrasion of the textile fibers, and was used for comparison purposes. Fabrics, yarns, and fibers were analyzed microscopically and photomicrographic records were kept of the type and extent of abrasive damage. Abraded and unabraded specimens were analyzed for changes in selected physical properties. All specimens were conditioned under standard atmospheric conditions of 70°F and 65 per cent relative humidity before physical analyses, and were abraded in a dry state. Standard laboratory methods recommended by ASTM (1), with certain modifications, were used for physical analyses.

Selection and Preparation of Specimens

The cotton and nylon fabrics used in this investigation were purchased from Testfabrics, Inc., and were of known weight and construction. Each fabric was divided into seven blocks, designated as A, B, C, D, E, F, or G. Areas within each block included specimens for the analyses of the unabraded and abraded fabrics at twelve abrasion levels. Two additional areas were included for replacement specimens.

Specimens were cut from the areas using a three and one-half inch die on the Thwing-Albert Sample Cutter. Designation of a specimen for a specific level of abrasion and physical analysis was done at random. Each specimen was coded and marked using a laundry marking pen, on the right side of the fabric. The following information was included on each specimen:

Warp direction:	indicated by an arrow
Fiber content:	C - cotton N - nylon
Area:	A through G
Specimen:	numbers one through sixty
Physical analysis:	
Breaking strength and elongation:	Br S
Weight:	W
Monsanto wrinkle recovery:	M
Yarn direction desired for analyses:	W or F
Abrasion level:	one through twelve

Abrasion

Specimens were abraded on the Schiefer Abrasion Testing Machine, using a spring steel abradant. The machine is equipped so that the amount of pressure on a specimen can be varied by interchanging and combining one, two, five, and ten pound weights. The abrasive action can be stopped at any desired number of revolutions, or will stop automatically when the destruction point of the fabric is reached. All specimens were mounted with the template, using a one and one-half inch plastic disc as the pressure foot, in order to insure equal tension on each specimen. Abrasion levels were established as a result of experimentation. Table I shows the twelve abrasion levels used for each fabric.

TABLE I

ABRASION LEVELS FOR COTTON AND NYLON FABRICS

Abrasion Level	Weight (pounds)	Number of Revolutions
	COTTON	
1	1	25
2		50
3		100
4		300
5		500
6		1,000
7	3	100
8		300
9		500
10		1,000
11	5	100
12		300
	NYLON	
1	1	100
2		300
3		500
4	3	100
5		300
6		500
7		1,000
8	5	100
9		300
10		500
11		1,000
12	10	5,000

Microscopic Analyses of Fabrics Before and After Abrasion

Microscopic analyses of cotton and nylon fibers, yarns, and fabrics before and after abrasion were done with an American Optical Company Series 4 Microstar trinocular microscope. A photomicrographic record of fibers, yarns and fabrics was obtained of unabraded specimens, and specimens from each abrasion level by use of a 35 mm camera attached to the vertical tube of the trinocular body of the microscope. Substage illumination was used for microscopic examination and for the photomicrographs rather than surface lighting in order to obtain a better overall picture of the fabrics, yarns, and fibers. Three photomicrographs were taken of fibers, yarns, and fabrics at each abrasion level, and from the unabraded fabric. The films were developed, and the best one was then chosen to be printed.

Examination of abraded and unabraded fabrics was done using a five power objective, and ten power eyepieces. Analysis was done on the specimens that were designated for determination of weight per square yard. The specimens were placed on the stage of the microscope and held in place with magnets. Slides and coverglasses were not used with fabrics. The difference, between the readings on the fine adjustment knob when the microscope was focused on the loose fiber ends and when it was focused on the surface of the fabric, was noted and recorded as an indication of the extent of damage to the fabric structure. Ten separate microscopic fields were examined on unabraded and abraded fabrics.

Yarns from abraded and unabraded fabrics were secured to microscope

slides for observation. Yarn specimens were taken from the specimens designated for determination of wrinkle recovery after specimens of the proper size had been removed. Yarns were examined under the microscope using a five power objective, and ten power eyepieces. The disorder of the fibers within the yarns was noted. Fibers, also taken from samples designated for determination of wrinkle recovery, were mounted on slides and fixed in place with clear nail polish, and were examined with a forty-three power objective, and ten power eyepieces. The fibers were examined for the kind and degree of abrasive damage evidenced.

Physical Analyses of Fabrics Before and After Abrasion

Unabraded specimens, and abraded specimens from each level were analyzed and compared for weight per square yard, wrinkle recovery, breaking strength, and elongation. Because of the small size of the abraded area, one inch squares, cut from the center of the specimen, were used to determine the weight per square yard. Wrinkle recovery of the specimens was determined by use of the Monsanto wrinkle recovery apparatus. Breaking strength and elongation were assessed by the grab test on the Scott Tester Model J. Jaw faces were one inch in width, and were moved to within one inch of each other because of the small size of the abraded area. It was necessary to use the entire circular specimen for the determination of breaking strength and elongation instead of a rectangle because of the limited abraded area.

Interpretation of Results

The mean and standard deviation of each of the physical analyses at each abrasion level were calculated and recorded. The abrasive damage at each abrasion level; the general appearance of the fabric, height of surface fibers, yarn disturbance, type and extent of damage done to fibers, was recorded. Cotton and nylon fibers, yarns, and fabrics were compared as to kind of abrasive damage, evidenced by microscopic and physical analyses, and the rate of progression of damage.

CHAPTER IV

RESULTS AND DISCUSSION

The effects of progressive abrasive action upon cotton and nylon fabrics, yarns and fibers were studied by microscopic observation, and by an investigation of changes in selected physical properties.

The cotton fabric used during this investigation was bleached muslin, with a weight of 3.2 ounces per square yard. The method of fabric construction was a plain weave, with eighty-eight warp yarns per inch, and eighty filling yarns per inch. Both warp and filling yarns were single-ply. A spun nylon fabric was also used. This fabric was constructed in a plain weave, with a two-ply warp yarn and a single-ply filling yarn. The nylon fabric had a weight of 3.8 ounces per square yard, and had a thread count of sixty-eight warp yarns per inch, and fifty-four filling yarns per inch.

It was necessary to clean the abradant at periodic intervals during the abrasion of both cotton and nylon fabrics. Loose fibers and large particles of detrius were found in the abradant at the higher abrasion levels. Their presence between the abradant and the fabric reduced the number of contact points, and intensified the stresses of abrasion. In preliminary work, it was found that large amounts of detrius drawn out of abraded cotton fabrics intensified the stresses to such a degree that an early breakdown of the fabric structure occurred. Detrius and fiber particles drawn out of the nylon fabrics were not large enough to cause failure of the fabric.

Microscopic Analyses

Cotton and nylon fabrics, yarns, and fibers from progressive levels of abrasion were analyzed microscopically, and photomicrographic records were kept of the type and extent of abrasive damage observed. Because of the limited depth of focus of both the microscope and camera, not all of the details in the fabrics and yarns were clearly seen in the photomicrographs. The thickness of the yarns, their twist and crimp, and the manner in which the fibers spread out of the yarns all combined to make it difficult to photograph all of the details desired. The thickness of the yarns and fabrics necessitated such an intense light coming from below the fabric to make as much detail visible as possible, that it tended to "wash out" many of the free-standing fibers from the yarns, and the fibers filling in the interstices within the fabrics. The presence of these fibers is discernible in the photomicrographs, though not in clear detail.

Cotton Fabrics

Microscopic examination of unabraded cotton fabrics revealed variations in degree of twist and yarn diameter. Fiber diameters were seen to vary also, with a small number being extremely fine, and showing little discernible lumen. Small noils were scattered throughout the fabric. Loose fiber ends were easily seen above the surface of the fabric, but exhibited no consistent pattern of location, concentration, length, or direction. The unabraded fabric shows the manner in which the outer layers of fibers pulled away from the yarn and filled in the fabric

interstices (Plate I, Fig. 1).

There was little observable difference in general appearance between the unabraded fabrics and fabrics at level one. The fabric at level one (1 pound, 25 revolutions) shows a general tangle of loose surface fibers (Plate I, Fig. 2). Damage observed at this level occurred primarily in the fibers. The fabric at level two (1 pound, 50 revolutions) exhibits variations in the twist of the yarns (Plate I, Fig. 3). The yarns exhibiting a small amount of twist appeared to loosen and allow surface fibers to continue filling in the fabric interstices as abrasion progressed through level five. Loose fiber ends observed at level three (1 pound, 100 revolutions) appeared longer than had been seen before, and remained close to the surface of the fabric. Where nails occurred on the abraded surface, those fibers exhibited a distinctly chewed and fragmented appearance. The increased thickness of the fabric structure at these locations may have brought about more intense abrasive forces, and consequently caused more severe damage. A fabric at level four (1 pound, 300 revolutions) shows an off-grain effect that occurred in a few abraded specimens (Plate I, Fig. 5). This effect was assumed to have occurred as a result of the specimen not being held as firmly as others by the clamp. The number and length of loose fibers increased in level five (1 pound, 500 revolutions). The fabric at level five (Plate I, Fig. 6) shows an increased tangle of fibers observed on the fabric as the yarns loosened and their twist decreased. Damage incurred by fabrics at level six (1 pound, 1,000 revolutions) appeared to be more intensive than extensive. Severe damage occurred primarily to the high, loose fibers,

EXPLANATION OF PLATE I

Photomicrographs of Cotton Fabrics Before and After Abrasion

(Magnification 12.5 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

with the protected surface fibers and those in the yarns receiving little damage.

Increased damage to the fabric, both in yarn structure and the tangled appearance of fibers was observed as the pressure applied during abrasion was increased at level seven (3 pounds, 100 revolutions). This effect may be seen by a comparison of fabrics at level three (Plate I, Fig. 4), and level seven (Plate II, Fig. 1), both of which were abraded for one hundred revolutions. The density and length of loose fibers increased in level eight (3 pounds, 300 revolutions). The extremely tangled effect of a noil, and an almost completely disintegrated yarn adjoining the noil may be seen in the photomicrograph of the fabric at level eight (Plate II, Fig. 2). Little change was observed at level nine (3 pounds, 500 revolutions), except for the continued filling in of the fabric interstices. The number of loose fibers at levels ten (3 pounds, 1,000 revolutions) and eleven (5 pounds, 100 revolutions) increased to such a degree that it was difficult to record details of fabric structure. Many interstices had completely filled in at level twelve (5 pounds, 300 revolutions) and the surface was well covered with loose, tangled fibers.

Cotton Yarns

Microscopic observation of yarns from unabraded specimens revealed a few short fibers wrapped around the yarns at right angles to the yarn axis. These fibers were not held by the yarn structure, and their position was not considered to be an indication of abrasive damage incurred by the yarn structure. Unabraded yarns (Plate III, Fig. 1; Plate IV, Fig. 1)

EXPLANATION OF PLATE II

Photomicrographs of Cotton Fabrics After Abrasion

(Magnification 12.5 times)

Fig. 1. Abrasion level 7.

Fig. 2. Abrasion level 8.

Fig. 3. Abrasion level 9.

Fig. 4. Abrasion level 10.

Fig. 5. Abrasion level 11.

Fig. 6. Abrasion level 12.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

EXPLANATION OF PLATE III

Photomicrographs of Cotton Warp Yarns Before and After Abrasion

(Magnification 6.25 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

EXPLANATION OF PLATE IV

Photomicrographs of Cotton Filling Yarns
Before and After Abrasion

(Magnification 6.25 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

PLATE IV

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

show a few fibers loosened slightly from the yarn structure. There was little observable difference between yarns from unabraded specimens, and yarns from level one. The manner in which fibers pulled away from the surface of the yarns may be observed in the warp yarn at level two (Plate III, Fig. 3). These loose outside fibers were the ones which spread out and filled in the fabric interstices. Fiber ends were beginning to pull out of the yarn at level three (Plate III, Fig. 4; Plate IV, Fig. 5).

The differences between the warp and filling yarns at level four may have been due in part to the angle at which the yarns were secured to the slide. The warp yarn is seen from the top (Plate III, Fig. 5), and shows long fibers pulling away from the sides of the yarn. The filling yarn (Plate IV, Fig. 5) is seen from the side, and shows clearly the crimp in the yarn, and the height of some of the loose fiber ends. The number and height of fiber ends which were pulled out of the yarn structure progressed at levels five and six.

Filling yarns showed more disintegration than warp yarns at levels seven through ten. This pattern was reversed at level twelve, where damage to warp yarns appeared greater. The effect of increasing weight may be seen by a comparison of warp yarns at levels four (Plate III, Fig. 5), and twelve (Plate III, Fig. 13). The loose fibers at level four remained oriented with the yarn axis, while those in level twelve became tangled, and exhibited many more free ends.

Cotton Fibers

The natural form of cotton fibers, often described as a twisted ribbon, consists of a dark central core, and a cuticle discernible as a thick, clear outer ridge (Plate V, Fig. 1, and Plate VI, Fig. 1). Abrasive damage was slight at level one, with fragmentation the most common form of damage observed. The term fragmentation was used to describe a lateral splitting of the fiber that was more coarse in nature than fibrillation. Other damage observed included isolated fibers which appeared flattened and transparent, and the presence of detrius, or loose damaged fiber particles. A fiber at level one, (Plate IV, Fig. 2) shows the cuticle pulling away from the central part of the fiber. Fabrics observed at level two showedno increase in fragmentation or the occurrence of transparent fibers. A few examples of fibrillation were observed, and isolated fibers exhibited a rough or chewed appearance.

The number of damaged fibers increased at level three. Fragmentation and chewed surfaces were the most common forms of damage observed. There appeared to be some movement in the loose surface fibers during abrasion, as evidenced by the changing fiber orientation, and tangled appearances at various levels. The fiber from a warp yarn at level four (Plate V, Fig. 5), shows a cut side. Previous studies of abrasion resistance of fabrics by Backer (2) and Stoll (18) indicated that fiber cutting occurred when fine projections were present on the abrasive surface. The steel spring abradant used offered no such projections. No satisfactory explanation can be given for the presence of these cuts. The fiber at level five (Plate V, Fig. 6) shows a roughened

EXPLANATION OF PLATE V

Photomicrographs of Cotton Fibers From Warp Yarns Before and After Abrasion

(Magnification 107.5 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

Fig. 1

Fig. 2

Fig. 3

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Fig. 7

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Fig. 10

Fig. 11

Fig. 12

Fig. 13

or chewed appearance and an accumulation of detrius. The increase in number of revolutions from three hundred at level four to five hundred at level five approximately doubled the amount of fragmentation, and almost tripled the amount of fibrillation observed. There was a slight increase of fragmentation in level six, while the number of examples of fibrillation was approximately doubled. Fibrillation at this level occurred primarily in the middle of fibers, with fragmentation more common at fiber ends. The fiber from warp yarn at level six (Plate V, Fig. 7) shows a peculiar watery appearance, which resembles somewhat the transparent fibers observed previously. Fibers from filling yarns showed a loss in twist, a change observed in several fibers as the intensity of abrasion increased. The presence of detrius in the fibers, and isolated examples of mashed fiber ends were further evidence of abrasive damage.

Microscopic observation of fibers at level seven revealed fragmentation to be the most prevalent form of damage. Other fiber damage observed included fibrillation, cuts, chewed surfaces, isolated mashed ends, and a small amount of detrius. An increase in the number of revolutions in level eight increased the number of examples of fragmentation observed. No examples of fibrillation were observed at this level, but other damage was noted in the form of cuts, chewed sides, transverse ridges, and mashed ends. A fiber from a warp yarn (Plate V, Fig. 9) appears to have a slightly roughened cuticle. An increase in the number of revolutions at level nine increased the number of fibers showing fragmentation, fibrillation, cuts, and chewed sides. Transverse ridges

may be seen in fibers from warp yarns (Plate V, Fig. 9) and filling yarns (Plate VI, Fig. 9) at this level. The number of examples of fragmentation found in fibers at level ten was almost double that observed at level nine. More fibers were observed showing fibrillation than fragmentation. The number of fibers showing cuts, chewed sides, and detrius decreased. Fibers from warp yarns (Plate V, Fig. 11), and filling yarns (Plate VI, Fig. 11) show fibers which have darkened longitudinal bands, and little natural twist remaining.

Increasing the pressure at level eleven caused an increased amount of damage. A higher number of examples of fragmentation and fibrillation was noted than had been observed previously. Fibers showing cuts, chewed sides, mashing and detrius were still present. A fiber from a warp yarn (Plate V, Fig. 12) shows the transverse ridges to be deeper than observed before. The increased weight at level twelve produced approximately four times the number of damaged fibers observed in level four, and about double that found in level eight, although each level was abraded for three hundred revolutions. Fiber damage included the largest amounts of fibrillation, fragmentation, and chewed sides which had been observed. A fiber from a filling yarn (Plate VI, Fig. 13) at level twelve shows in good detail the transparent fiber that had been observed at previous levels. One part of the fiber shows the dark lumen still present, while the rest of the fiber appears to have been split, and the lumen stripped out.

EXPLANATION OF PLATE VI

Photomicrographs of Cotton Fibers From Filling Yarns Before and After Abrasion

(Magnification 107.5 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

Fig. 1

Fig. 2

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Fig. 11

Fig. 12

Fig. 13

Nylon Fabrics

Microscopic examination of unabraded nylon fabrics showed the fabric interstices to be small and fairly well filled in with fibers. An irregular tangle of loose surface fibers was also noted (Plate VII, Fig. 1). A large amount of the damage caused by abrasion was evidenced as fiber damage rather than damage to the fabric structure. As fabrics were abraded, the number of loose surface fibers increased, and became more orientated toward each other. Surface fibers of fabrics at level one (1 pound, 100 revolutions) and level two (1 pound, 300 revolutions) showed little orientation; some orientation was observed at level three (1 pound, 500 revolutions), and increased through level five (3 pounds, 300 revolutions). Fabrics at levels two (Plate VII, Fig. 3) and three (Plate VII, Fig. 4) show the manner in which the nylon yarns slipped from their original positions and caused an irregular spacing of yarns in the fabric.

As the number of revolutions increased at level six (3 pounds, 500 revolutions), many fiber ends stood up at right angles to the surface of the fabric. At level six, and following levels, it became increasingly difficult to focus clearly upon the surface of the fabrics because of the density of the intervening loose fibers. Fabrics at higher levels of abrasion, especially levels eight (5 pounds, 100 revolutions) and ten (5 pounds, 500 revolutions) give a good indication of the tangled state of the loose fibers found on the surface of the fabrics, (Plate VIII, Figs. 2 and 4).

EXPLANATION OF PLATE VII

Photomicrographs of Nylon Fabrics Before and After Abrasion

(Magnification 12.5 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

EXPLANATION OF PLATE VIII

Photomicrographs of Nylon Fabrics After Abrasion

(Magnification 12.5 times)

Fig. 1. Abrasion level 7.

Fig. 2. Abrasion level 8.

Fig. 3. Abrasion level 9.

Fig. 4. Abrasion level 10.

Fig. 5. Abrasion level 11.

Fig. 6. Abrasion level 12.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Nylon Yarns

Photomicrographs of warp and filling yarns from unabraded fabrics served to emphasize the difference in size of the two yarns. Both yarns appear tightly twisted, with fibers at the edges of the yarns still packed closely together (Plate IX, Fig. 1, Plate X, Fig. 1). An examination of yarns from level one showed a few fibers being pulled out of the yarn, with the main part of the yarn holding together. At level two, a few fibers were observed wrapped around the filling yarns at right angles to the yarn axis. The filling yarns at levels three and four seemed to be pulling apart at a faster rate than did the warp yarns. Warp yarns at level five exhibited a general loosening tendency, with fiber ends as well as sides pulled out of the yarn. Disintegration of the warp yarn at level six exceeded that of the filling yarn.

The different manner in which warp and filling yarns were affected by abrasion was best illustrated by warp and filling yarns at abrasion levels eight and nine. Fibers from the smaller filling yarns were pulled out of the yarns further, and often stood up at right angles to the yarn axis (Plate X, Figs. 9 and 10). Fibers from the warp yarns were pulled out of the yarn more slowly, with a general loosening trend before entire fibers were lost (Plate IX, Figs. 9 and 10). The number of loosened fibers appeared considerably decreased in level ten (Plate IX, Fig. 11) suggesting the loss of some fibers from the yarn structure. Yarns from level 12 showed a general loosening trend throughout the yarn, with fewer fibers being pulled out of the yarn structure.

EXPLANATION OF PLATE IX

Photomicrographs of Nylon Warp Yarns Before and After Abrasion

(Magnification 6.25 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

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Fig. 6

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Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

EXPLANATION OF PLATE X

Photomicrographs of Nylon Filling Yarns
Before and After Abrasion

(Magnification 6.25 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

Fig. 1

Fig. 2

Fig. 3

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Fig. 5

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Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Nylon Fiber

The majority of fibers from unabraded fabrics exhibited the straight, smooth, cylindrical appearance typical of synthetic fibers. The presence of delustrants in the fibers was also noted. A few fibers were seen to deviate from this form, with occasional bubbles and burst ends observed. Bubbles were noted by Ford (11) in a study of stresses received by synthetic fibers. Their presence in fibers before fabrics were abraded was assumed to be a result of the normal stresses encountered in fiber production and fabric construction. The number of bubbles increased as abrasion progressed, indicating the action of increased stresses during abrasion. Burst ends were later seen to be the result of the rupture of bubbles.

The number of bubbles and burst ends increased through levels one and two. Several fibers were observed which appeared to be sharply bent away from their original direction. The abrupt change noted in the orientation of these fibers may have been an indication of a change in the molecular orientation of the fiber. Detrius was present in high loose fibers, and isolated fibers were observed which appeared to be tied in a knot. The fiber at level one (Plate XI, Fig. 2) shows the beginning of a bubble within the fiber. Detrius appears on the fiber at level two (Plate XI, Fig. 3).

Most high loose fibers at level three appeared to have uneven, although not bent sides, and were more orientated to each other than fibers in the previous two levels. The presence of bubbles and burst ends was comparatively constant. Other fiber damage included bent forms

EXPLANATION OF PLATE XI

Photomicrographs of Nylon Fibers From Warp Yarns
Before and After Abrasion

(Magnification 107.5 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

Fig. 1

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Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

and the presence of detrius. The fiber from a warp yarn (Plate XI, Fig. 4), shows the flattened appearance that was seen in isolated fibers only at this level.

Increased pressure at level four did not produce a higher number of bubbles, but did increase the number of burst ends slightly. Bent fibers and detrius were again present. The bent character observed in several fibers may be seen in the fiber from warp yarn (Plate XI, Fig. 5). The fiber from a filling yarn shows uneven sides and the formation of a bubble (Plate XII, Fig. 5). Only slight increases in the numbers of damaged fibers were noted as the number of revolutions was increased at level five. The fiber from a warp yarn at level five (Plate XI, Fig. 6) contains a bubble, and is carrying detrius.

The number of bubbles observed at level six was double that seen in level three, but the number of burst ends increased only slightly. Damage was also noted in the form of bent fibers, detrius, and cut sides. Isolated examples of knotted fiber ends were observed at levels six and seven. The fiber from a warp yarn (Plate XI, Fig. 7) shows a bubble in the process of rupturing. The number of bubbles and burst ends showed little change as the number of revolutions was increased at level seven. There was a slight increase in the number of cut fibers and the amount of detrius observed. Fibers exhibiting a chewed or roughened surface were noted for the first time.

The number of bubbles increased as the pressure was increased at level eight. The number of burst ends was the same as in level one. Bent fibers, chewed fibers, and detrius were also observed. As the number

of revolutions increased at level nine, the number of bubbles which were observed decreased, and the number of burst ends and bent fibers remained constant. The amount of detrius was more than double that of the previous level. The fiber from a filling yarn shows a dark shadow on the surface of the fiber (Plate XII, Fig. 10). This shadow indicated a deviation from the smooth surface of the fiber, either as a projection on the fiber surface, or a depression in the fiber. The fiber is also considerably narrower at one point, and appears to be beginning to bend at this location.

Fibers observed at level ten exhibited about twice the number of burst ends that were seen in the previous level. The number of bubbles, bent fibers, and the amount of detrius continued to increase. Occasional fibers appeared knotted, or exhibited chewed appearances.

Damage to fibers was not noticeably heightened by an increase in the number of revolutions at level eleven. A knot appears in the fiber from a filling yarn (Plate XII, Fig. 12). Knots were observed in fairly consistent numbers in both abraded and unabraded specimens, and were not believed to be the result of abrasive action.

Observation of fibers at level twelve revealed the lowest number of bubbles that was observed at any abrasion level, and an increase in the number of burst ends. The lower number of bubbles and increased numbers of burst ends in levels ten through twelve indicated that abrasive stresses may have developed to such a degree at these levels that bubbles were formed and ruptured at a faster rate than before, leaving more ruptured ends when abrasion was ceased. The largest number of chewed

EXPLANATION OF PLATE XII

Photomicrographs of Nylon Fibers From Filling Yarns Before and After Abrasion

(Magnification 107.5 times)

Fig. 1. Unabraded.

Fig. 2. Abrasion level 1.

Fig. 3. Abrasion level 2.

Fig. 4. Abrasion level 3.

Fig. 5. Abrasion level 4.

Fig. 6. Abrasion level 5.

Fig. 7. Abrasion level 6.

Fig. 8. Abrasion level 7.

Fig. 9. Abrasion level 8.

Fig. 10. Abrasion level 9.

Fig. 11. Abrasion level 10.

Fig. 12. Abrasion level 11.

Fig. 13. Abrasion level 12.

Fig. 1

Fig. 2

Fig. 3

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Fig. 10

Fig. 11

Fig. 12

Fig. 13

fibers and greatest amount detrius were observed at this level, suggesting the presence of more intense destructive forces than had been noted before. The fiber from a warp yarn (Plate XI, Fig. 13) shows a severely ruptured fiber end. The fiber from a filling yarn (Plate XII, Fig. 13) shows an uneven surface, and the presence of a large amount of detrius.

Physical Analyses

Unabraded and abraded cotton and nylon fabrics were analyzed for changes in breaking strength, elongation, wrinkle recovery, and weight. Standard laboratory procedures recommended by ASTM (1), with the modifications described in the Method of Procedure, were used for all physical analyses. The results of those analyses are shown in Table II.

Breaking Strength

The warp breaking strength of the unabraded cotton fabric was 70.8 pounds and the filling was 40.7 pounds. Breaking strength generally decreased with an increase in abrasive stresses, though not in a regular or uniform manner. Warp breaking strength for fabrics abraded under one pound of pressure decreased from 71.4 pounds at levels one to 65.4 pounds at level five, followed by an increase to 73.0 pounds at level six. This was the highest breaking strength obtained for abraded or unabraded cotton fabrics. When the pressure was increased to three pounds, breaking strength varied from 68.6 pounds at level seven to 67.3 pounds at level ten. Fabrics abraded under the increased pressure at levels eleven

TABLE II

BREAKING STRENGTH, ELONGATION, WRINKLE RECOVERY AND WEIGHT OF COTTON AND NYLON FABRICS AT PROGRESSIVE LEVELS OF ABRASION

Abrasion Level	Breaking Strength pounds				Elongation per cent				Wrinkle Recovery degrees				Weight oz./sq/ yd.	
	W*	SD**	F***	SD	W	SD	F	SD	W	SD	F	SD		SD
							COTTON							
Unabraded	70.8	3.89	40.7	1.71	15.0	0.00	19.5	1.50	100.1	11.18	101.7	5.30	3.2	0.04
1	71.4	1.05	40.2	1.51	13.5	1.37	16.5	2.47	95.2	6.21	96.3	8.75	3.2	0.06
2	70.8	1.40	41.0	2.81	12.5	1.76	26.0	4.14	96.9	7.34	98.5	5.34	3.2	0.07
3	70.4	4.21	38.4	1.83	13.0	1.50	20.0	2.48	96.9	6.02	96.1	8.14	3.2	0.03
4	70.4	1.63	38.5	1.93	13.0	1.50	19.0	1.38	96.7	4.09	104.7	8.37	3.2	0.04
5	65.4	3.31	39.1	5.14	15.0	0.00	19.5	2.12	94.1	9.86	101.5	0.08	3.1	0.07
6	73.0	5.17	36.5	8.15	14.5	1.50	20.5	2.08	101.5	6.50	102.4	5.03	3.1	0.04
7	68.6	5.63	39.7	4.98	14.5	1.50	19.0	1.38	98.1	9.04	98.4	9.81	3.2	0.04
8	71.4	1.61	36.0	6.71	14.0	1.30	20.0	0.00	95.3	10.63	97.3	4.97	3.1	0.03
9	61.3	8.34	28.8	7.79	12.5	0.00	17.5	1.31	98.7	7.52	99.6	8.64	3.2	0.04
10	67.3	1.56	31.2	10.58	13.0	1.50	16.0	1.10	98.1	12.66	97.9	9.04	3.1	0.05
11	67.3	2.45	41.8	2.91	14.5	2.08	17.5	0.00	101.4	6.99	96.0	5.87	3.2	0.04
12	66.4	3.34	36.7	9.20	13.0	1.50	18.1	1.44	96.8	6.62	94.9	5.01	3.2	0.08
							NYLON							
Unabraded	141.4	2.74	82.4	5.61	74.0	3.87	60.0	3.98	107.7	8.47	120.3	13.43	3.8	0.05
1	144.3	3.63	80.0	5.06	77.0	2.74	60.0	5.31	119.7	9.77	126.2	23.48	3.8	0.09
2	146.6	4.51	81.9	2.30	73.0	2.66	59.0	2.36	119.8	18.46	111.0	28.87	3.8	0.04
3	143.4	3.66	79.7	2.31	76.5	3.79	56.5	3.78	119.7	18.99	129.3	29.02	3.8	0.05
4	143.3	5.91	77.0	1.43	68.5	4.72	56.0	3.66	112.3	24.76	112.3	14.14	3.8	0.06
5	146.1	4.35	82.5	5.14	73.0	5.42	57.5	4.96	116.1	14.44	117.0	20.66	3.8	0.05
6	143.3	7.98	79.1	2.24	74.1	6.28	53.5	2.24	110.3	10.53	124.9	15.20	3.8	0.05
7	139.2	3.29	79.5	1.10	73.5	3.57	55.0	2.50	114.0	15.46	124.8	21.95	3.8	0.01
8	140.1	7.63	78.6	3.11	72.5	2.21	53.5	2.81	113.8	20.57	109.4	15.76	3.8	0.10
9	137.1	1.83	78.4	3.44	65.5	3.25	53.5	2.84	110.9	12.07	120.3	18.44	3.8	0.06
10	142.2	4.69	77.1	4.31	71.0	3.79	50.0	1.77	107.1	13.36	115.7	15.32	3.8	0.07
11	139.1	6.71	76.6	4.04	71.0	3.31	51.1	1.37	114.0	18.94	111.6	16.16	3.8	0.06
12	111.2	9.29	76.5	3.59	46.5	3.20	49.0	4.18	96.9	6.97	104.5	22.90	3.7	0.04

*Warp **Standard Deviation ***Filling

and twelve exhibited a slight decrease in breaking strength from 67.3 pounds to 66.4 pounds.

Fabrics abraded under one pound of pressure decreased in filling breaking strength from 40.2 pounds at level one to 36.5 pounds at level six. Breaking strength for fabrics abraded under three pounds of pressure showed a decrease from 39.7 pounds at level seven to 28.8 pounds at level nine, followed by an increase to 31.2 pounds at level ten. Fabrics at levels using five pounds of pressure decreased in breaking strength from 41.8 pounds to 36.7 pounds at level twelve.

Nylon fabrics analyzed for changes in breaking strength showed an overall decrease in warp breaking strength with increased abrasion, and an overall decrease in filling breaking strength for fabrics abraded under five pounds of pressure. The average breaking strength of the unabraded nylon fabric was 141.4 pounds for warp, and 82.4 pounds for filling. Nylon fabrics abraded under one pound of pressure showed a decrease in warp breaking strength from 144.3 pounds at level one to 143.4 pounds at level three. Fabrics subjected to three pounds of pressure decreased in breaking strength from 143.3 pounds at level four to 139.2 pounds at level seven. Levels two and five, both of which had been abraded for three hundred revolutions, showed a slight increase in breaking strength. Fabrics abraded under five pounds of pressure decreased in breaking strength from 140.1 at level eight to 139.1 pounds at level eleven. An increase in pressure and number of revolutions at level twelve brought the breaking strength of nylon to its lowest point, 111.2 pounds.

Filling breaking strength showed little consistency of change until the pressure was increased to five pounds. Breaking strength at level eight was 78.6 pounds, and decreased to 76.6 pounds at level eleven. Fabrics at level twelve were not materially affected by increased pressure or number of revolutions.

Elongation

Elongation of unabraded cotton fabrics averaged 15.0 per cent for warp, and 19.5 per cent for filling. Warpwise, fabrics abraded under one pound of pressure showed little change in elongation from 13.5 per cent at level one to 14.5 per cent at level six. Elongation decreased from 14.5 per cent to 13.0 per cent when fabrics were subjected to three pounds and five pounds of pressure. Filling elongation for cotton fabrics abraded under one pound of pressure increased from 16.5 per cent at level one to 20.5 per cent at level six, with an unexplained increase to 26.0 per cent at level two. Fabrics subjected to three pounds of pressure showed a decrease in filling elongation from 19.0 per cent at level seven to 16.0 per cent at level ten, while those abraded under five pounds of pressure showed an increase from 17.5 per cent at level eleven to 18.1 per cent at level twelve.

The average elongation of unabraded nylon fabrics was 74.0 per cent for warp, and 60.0 per cent for filling. The pattern of change in the elongation of warp yarns was somewhat erratic, with no clear loss or gain in elongation observed. Warpwise the elongation varied from 77.0 per cent at level one to 46.5 per cent at level twelve. Filling

elongation decreased in the same pattern for one, three, or five pounds of pressure. Each increase in pressure reduced the elongation, as did increasing the number of revolutions up to one thousand, where a slight increase was noted. Elongation decreased from 60.0 per cent for the unabraded fabric and level one, to 49.0 per cent at level twelve.

Wrinkle Recovery

Changes in the wrinkle recovery of cotton and nylon fabrics at the various abrasion levels showed little consistency in rate or direction of change. The average wrinkle recovery of cotton fabrics before abrasion was 100.1 degrees for the warp, and 101.7 degrees for filling. The warp wrinkle recovery of abraded fabrics was lower than that of unabraded fabrics at levels six and eleven. Wrinkle recovery of fabrics subjected to one pound of pressure varied from 95.2 degrees at level one to 101.5 degrees at level six. No overall change was noted for fabrics abraded under three pounds of pressure, with levels seven and ten showing a warp wrinkle recovery of 98.1 degrees. An increase in the pressure to five pounds decreased the wrinkle recovery to 96.8 degrees in level twelve. Wrinkle recovery in the filling fluctuated more than for the warp, ranging from 104.7 degrees at level four to 94.9 degrees at level twelve. The low pressure and high number of revolutions at levels four through six increased the wrinkle recovery over that of the unabraded fabric.

The average wrinkle recovery of unabraded nylon fabrics was 107.7 degrees for warp and 120.3 for filling. Warp wrinkle recovery of abraded

fabrics was higher than the unabraded fabrics except at level twelve, which averaged 96.9 degrees. There was little change in the wrinkle recovery of fabrics abraded under one pound of pressure. Warp wrinkle recovery of the fabrics abraded under three and five pounds of pressure ranged from 116.1 to 107.1 degrees, but showed no regular pattern of change.

An overall increase in filling wrinkle recovery of abraded nylon fabrics was seen, although results at individual levels fluctuated erratically. As was noted in the warp yarns, one pound of pressure brought about little change. Filling wrinkle recovery of fabrics abraded under three pounds of pressure increased from 112.3 degrees at level four to 124.8 degrees at level seven, with very little change noted from level six to seven. The wrinkle recovery of fabrics subjected to five pounds of pressure did not exhibit a regular pattern of loss or gain.

Weight

The weight of cotton and nylon fabrics decreased only slightly with progressive abrasion. The unabraded cotton fabric weighed 3.2 ounces per square yard, and the nylon fabric weighed 3.8 ounces per square yard. Cotton fabrics showed a slight decrease to 3.1 ounces per square yard at levels six and ten, which were abraded for one thousand revolutions. The weight of the nylon fabric was reduced to 3.7 ounces per square yard at level twelve.

CHAPTER V

SUMMARY OF RESULTS AND CONCLUSIONS

This investigation was designed to determine the effects of progressive abrasive action upon selected service qualities of cotton and nylon fabrics by microscopic and physical analyses. Abrasion levels for each fabric were established as a result of experimentation by varying the pressure and number of revolutions. Fabrics, yarns, and fibers were analyzed microscopically, and photomicrographic records were kept of the type and extent of abrasive damage observed. Unabraded and abraded specimens from each level were analyzed and compared for breaking strength, elongation, wrinkle recovery, and weight per square yard. Standard laboratory procedures, recommended by ASTM (1), with certain modifications, were used for all physical analyses.

Microscopic examination of unabraded cotton and nylon fabrics disclosed variations in the twist and diameters of yarns. The interstices of the nylon fabric were more filled in than those of the cotton fabric, apparently a result of less twist in the yarns. As abrasion progressed, the outer layers of fibers from the yarns were loosened and pulled to the fabric surface, eventually covering the surface with long, tangled fibers, and filling in the fabric interstices. The same pattern of abrasive damage was noted in cotton and nylon yarns, although at a slower rate in the nylon fabrics. Damage to warp and filling cotton yarns was balanced for specimens abraded under one pound of pressure. Filling yarns appeared to suffer more damage than warp yarns as the

pressure was increased. The same effect was noted in the nylon, where filling yarns also showed more damage. It appeared that the larger, two-ply warp yarns had greater cohesion, and were better able to withstand the stresses of abrasion, as had been suggested by McNally and McCord (15).

Microscopic examination of cotton fibers revealed abrasive damage in the forms of fragmentation, fibrillation, transparency, cuts, chewed appearances, mashing, transverse folds and cracks, and the presence of detrius. Fragmentation was noticed more often than fibrillation, except in specimens which had been abraded for one thousand revolutions, suggesting that more intense abrasive forces were required to cause fibrillation. A large number of fibers exhibited cuts and chewed appearances at the higher abrasion levels. It may have been that bending and rubbing actions between the tangled surface fibers caused these deformations of the fiber surfaces.

Examination of fibers from abraded nylon fabrics showed that loose surface fibers tended to lose their cylindrical shape with increased abrasive stresses. Other fiber damage observed in nylon fabrics included bubbles, burst ends resulting from the rupture of bubbles, sharp bends in fibers, chewed sides, cuts, and the presence of detrius.

Cut and chewed fibers appeared to be a result of external stresses, while fragmentation fibrillation, bubbles, burst ends, and bent fibers appeared to be the result of internal stresses. The occurrence of detrius and fibers which had been chewed and cut were the only types of abrasive damage that were seen in both cotton and nylon fibers. The molecular

construction of cotton, a natural fiber, and nylon, a man-made fiber, were so different that it was not possible to compare other types of fiber damage.

There was a general decrease in breaking strength of cotton and nylon fabrics with increased abrasive stresses. Microscopic examination of fibers from abraded fabrics showed the number of damaged fibers to be larger as increased abrasive stresses were applied, indicating that the decrease in breaking strength was partially a result of fiber damage within the fabric structure. Exceptions were noted in the warp breaking strength of cotton fabrics abraded for one thousand revolutions. Microscopic observation of abraded fabrics showed the tangled appearance of loose surface fibers to be advanced at these levels, which may have given the fabric added resiliency. It had also been suggested by Douglas (10) that increased availability of damaged cotton fibers might account for increased moisture absorbency. The ability of cotton to increase in strength as it absorbs moisture may have accounted for some of the increase in breaking strength observed at these levels. Breaking strength of cotton fabrics averaged about one-half that of the nylon at all but the highest abrasion level.

Elongation of cotton fabrics exhibited a slight tendency to increase when abraded under one pound of pressure, but other data were too erratic to ascertain a clear pattern of change. Elongation of nylon, fillingwise, decreased with increased pressure and number of revolutions. The elongation of nylon fabrics was three to five times greater than observed for the cotton fabrics.

Wrinkle recovery of cotton fabrics showed an increase for those specimens abraded under one pound of pressure, very little change for those abraded under three pounds of pressure, and a slight decrease for those subjected to five pounds of pressure. Wrinkle recovery data for nylon fabrics was not consistent. This lack of uniformity indicated variations in the fabric structure that was further evidenced in the microscopic analyses. There was not the regular increase in the number of damaged fibers as abrasion progressed that was noted in the observation of cotton fibers.

Cotton and nylon fabrics abraded at the highest number of revolutions exhibited slight losses in weight, suggesting that the length of abrasion was a more important cause of weight loss than the amount of pressure applied.

There did appear to be relationships between the type and extent of fiber and fabric damage, and changes in physical properties noted as a result of abrasive stresses. As this investigation was designed to be exploratory in nature, further research needs to be done to substantiate these relationships.

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MICROSCOPIC AND PHYSICAL ANALYSES OF SELECTED COTTON AND NYLON FABRICS BEFORE AND AFTER ABRASION

by

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This investigation was designed to determine the effects of flat abrasive wear on selected service qualities of cotton and nylon fabrics by microscopic and physical analyses and to determine relationships between the type and extent of fiber and fabric damage due to abrasion and the effects of abrasion upon selected physical properties of the fabrics. Abrasion levels for each fabric were established as a result of experimentation by varying the pressure and number of revolutions. Fabrics, yarns, and fibers were analyzed microscopically and photomicrographic records were kept of the type and extent of abrasive damage observed. Unabraded and abraded specimens from each level were analyzed and compared for breaking strength, elongation, wrinkle recovery, and weight per square yard. Standard laboratory procedures recommended by the American Society for Testing Materials, Committee D-13, with certain modifications, were used for physical analyses.

Microscopic examination of abraded fabrics showed that the outer layers of fibers of the yarns loosened and pulled away from the yarns as abrasion progressed. These fibers became tangled on the fiber surface, or filled in the fabric interstices. The larger two-ply nylon warp yarn offered the most cohesion and showed the least amount of damage. The nylon fabric showed a slower rate of disintegration than the cotton.

The high number of cotton fibers which showed cuts, chewed sides, and fibrillation, coupled with losses in breaking strength and elongation at high levels of abrasion indicated these forms of damage to be the most severe. Other damage included fragmentation, transparency, transverse folds and cracks, mashing, and the presence of detrius. The most severe forms of damage to nylon fibers appeared to be burst ends and chewed sides.

Other forms of damage observed were bends in fibers, loss of spherical shape, bubbles, cuts, and the presence of detrius.

There was a general decrease in breaking strength of cotton and nylon fabrics with increased abrasive stresses, except in cotton fabrics abraded at the highest level. Breaking strength of nylon fabrics was approximately twice that of the cotton. Elongation of cotton fabrics showed a slight decrease warpwise, with progressive abrasion. Nylon fabrics showed a decrease in filling elongation with increased pressure and number of revolutions.

The degree of wrinkle recovery of cotton fabrics increased when fabrics were abraded under one pound of pressure, and decreased when abraded under five pounds of pressure. The data for wrinkle recovery of nylon fabrics varied so greatly it was not possible to establish a pattern of change. Cotton and nylon fabrics showed a slight decrease in weight at levels having the highest number of revolutions.

There appeared to be certain relationships between damage observed microscopically and changes in physical properties. Further research needs to be done in order to substantiate these findings.